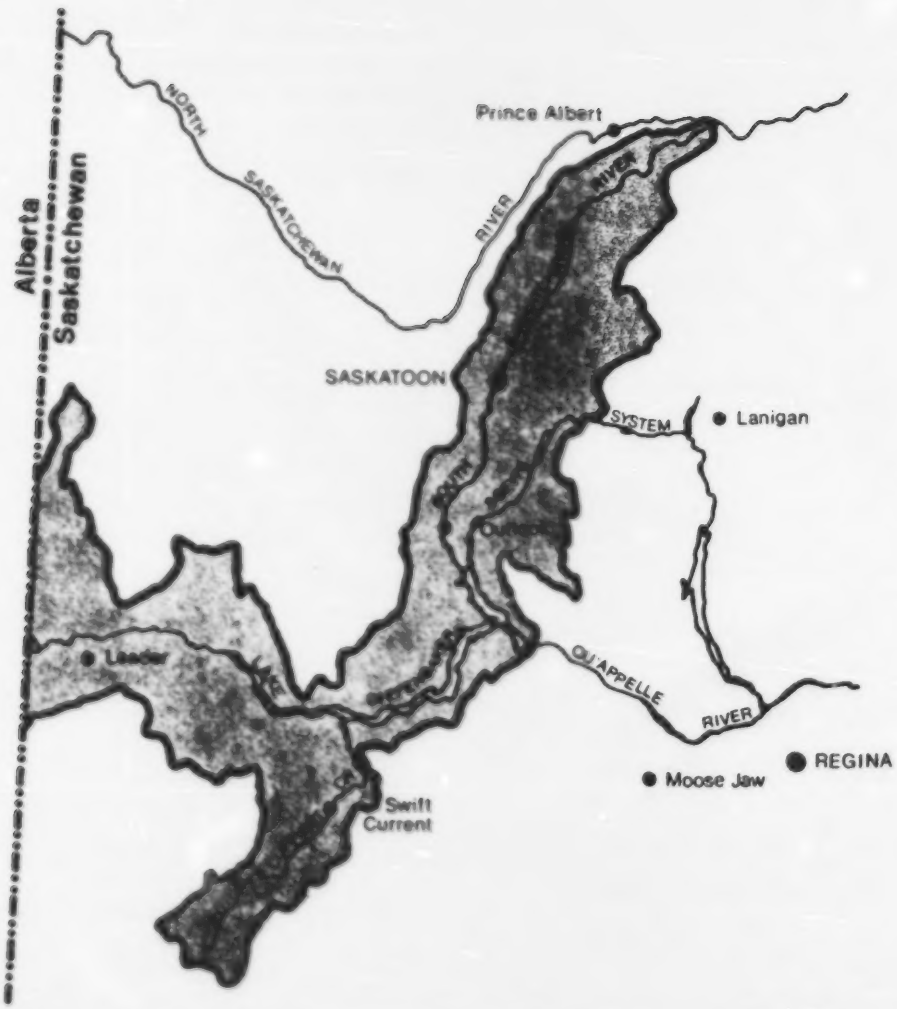
SOUTH SASKATCHEWAN RIVER BASIN STUDY



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MASS LOADING OF PHOSPHORUS TO LAKE DIEFENBAKER

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MASS LOADING OF PHOSPHORUS TO LAKE DIEFENBAKER

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EXECUTIVE SUMMARY

A detailed examination was made of the phosphorus loadings to Lake Diefenbaker, from the South Saskatchewan River. Monthly data from the South Saskatchewan River at Hwy. #41, Alt, and the Red Deer River at Bindloss, Alt. for the period 1975 to 1988 were used as well as weekly data from the South Saskatchewan River at Lemsford bridge from 1985 to 1988.

Comparison of the two data sets showed that the use of weekly data from Lemsford produced more accurate estimates of phosphorus than the use of monthly data from the other two locations. It was also found that approximately 84% of the annual total phosphorus load occurred during maximum runoff periods (April to July). It was concluded however that weekly data would only be necessary for the period of high loadings (April to July) and that monthly data would suffice during the other months.

When comparing the input of phosphorus to Lake Diefenbaker to the output of phosphorus it was concluded that the lake acts as a phosphorus sink for the basin. Over the period 1985 to 1988 the average accumulation of total phosphorus in lake sediments per year was 945 tonnes. Further examination showed that 45 to 55% of the accumulated phosphorus was bioavailable. This led to the conclusion that any change in the oxygen regime (extended oxygen depletion) in the lake would cause a significant deterioration in the trophic status. A depletion in the oxygen over extended periods would cause the release of a significant amount of settled phosphorus from the sediments.

The final conclusion of the report was that no water quality objective for phosphorus in the South Saskatchewan River upstream of Lake Diefenbaker was appropriate at this time. This conclusion was based on the fact that most of the phosphorus entering the lake via the South Saskatchewan River was the product of natural erosion and could not be controlled. If a water quality objective was developed in the future it should concentrate on dissolved phosphorus as apposed to total phosphorus. Dissolved phosphorus is more commonly caused by anthropogenic activity.

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1.0 Introduction

Lake Diefenbaker, a multi-use storage reservoir on the South Saskatchewan River (SSR), is the largest body of high quality water in southern Saskatchewan (Figure 1). The Lake has a capacity of 9.4 billion cubic meters, approximately twice the mean annual discharge of the South Saskatchewan River at the Alberta-Saskatchewan boundary. The long-term protection of thew water quality Lake Diefenbaker, which was filled in 1967 following completion of the Gardiner and Qu'Appelle Dams, is a priority of the Saskatchewan Government.

The report of a federal-provincial water quality study of Lake Diefenbaker and the Upper South Saskatchewan River (SE&PS et al. 1988) conducted during 1984 and 1985 indicated that the trophic status of Lake Diefenbaker ranged from mesotrophic in the upper reaches to oligotrophic in the lower reaches. The report concluded that phosphorus was the limiting factor to plant productivity in the lake. The maintenance of mesotrophic, or better, trophic status in Lake Diefenbaker was the objective recommended by the study.

Considerable effort has been spent on deriving phosphorus objectives for the South Saskatchewan River upstream of Lake Diefenbaker. There is general agreement that the objective should be based on phosphorus load, rather than concentration. The Prairie Provinces Water Board (PPWB Draft, 1987) suggested a total phosphorus (TP) load objective of 285 tonnes total phosphorus/annum (as P) (the combined loads of the South Saskatchewan and Red Deer Rivers). This objective was determined from OECD (1982) trophic probability curves, and was designed to maintain average in lake total phosphorus concentrations near 0.025 mg/L. This concentration coincided with the maximum probability of mesotrophic status.

SE&PS et al. (1988) using an alternative approach to the OECD relationships, stated that the critical phosphorus load from the two tributaries should not exceed 130 tonnes total phosphorus/annum (as phosphorus) during an average flow year.

A report presenting a Lake Diefenbaker trophic state model (SE&PS, 1988) suggested the use of a flow-dependent phosphorus load objective based upon trophic response curves derived for the Herbert Ferry area of the lake. Using this method, the objective would be approximately 300 tonnes total phosphorus/annum (as phosphorus) during an average flow year.

The relationship between incoming total phosphorus load and the trophic response of Lake Diefenbaker has been a subject of some controversy. The lake response model used to derive the

load objectives is based upon the average response of a very large number of lakes throughout the world to total phosphorus input. The precision of the response estimates is normally expected to be within an order of magnitude. One reason for this limited precision is due to variance in phosphorus bioavailability between waters. The fact that models based on total phosphorus tend to work is due to the fact that total phosphorus load is proportional to bioavailable phosphorus load (Sonzogni et al., 1982).

SE&PS et al. (1988) noted that 89 percent of the phosphorus entering Lake Diefenbaker annually was particulate phosphorus, of unknown bioavailability. It recommended that work be undertaken to determine the extent of bioavailablity of this major fraction.

One of the conclusions in SE&PS (1988) was that additional work was needed to determine the contribution of the sediments to the phosphorus budget for the lake. This study was proposed and designed to fill that gap in the original model. Taking a mass load approach to thephosphorus budget, allowed for the identification of mass difference in the input and output of phosphorus to a lake. The magnitude and source of this difference can then be examined. It can be assumed that if the mass difference is positive phosphorus is being generated by the lake or there are phosphorus sources that have not been taken into account. If the mass difference is negative the lake can be considered to be acting as a phosphorus sink. Although Serruya (1975) and Vollenweider (1976) used these methods to examine the nutrient budgets for lakes with striking results, few other authors have utilized it as a tool in trophic studies.

The objectives of this report are as follows:

1. to examine the phosphorus load (total and dissolved) entering Lake Diefenbaker based on two independent data sets (1975-1988, monthly sampling and 1985-1988 weekly sampling);

2. to compare phosphorus loads from the two data sets, and make recommendations for future monitoring protocols;

3. to examine the Phosphorus retention by the reservoir and determine whether the sediments are a phosphorus source or sink; and

4. to make recommendations on phosphorus objectives for the South Saskatchewan River upstream of Lake Diefenbaker.

2.0 Methodology

The South Saskatchewan River at Highway #41 (station 00AL05AK0001) and the Red Deer River near Bindloss (station 00AL05CK0001) have been sampled monthly since 1974 by Environment Canada, as part of an interjurisdictional monitoring program initiated by the Prairie Provinces Water Board. The stations are located in Alberta, just above the confluence of the two rivers. Hydrometric stations (05AK001 and 05CK004) are maintained at the two sites by Water Survey of Canada.

Local observers were contracted in late 1984 to collect nutrient samples from the South Saskatchewan River at Lemsford and Gardiner Dam outfall. Samples are collected according to Environment Canada standard protocols at approximate weekly intervals, with frequency, on occasion, increased during high discharge periods and decreased during periods of low discharge.

Total phosphorus (method code 15406) and dissolved phosphorus (method code 15103) have been analyzed since 1974. The methods involve colorimetry on an autoanalyzer with ammonium molybdate, ascorbic acid, and potassium antimonyl tartrate (NAQUADAT, 1987). The total and dissolved phosphorus analytical methods are identical with the exception of a preliminary 0.45 micron filtration step. Prior to 1980, samples for dissolved phosphorus were filtered in the laboratory. Since that time, the filtration have been done in the field. Analyses were done at the Water Quality Branch western regional laboratories in Calgary and Saskatoon.

The following equation has been used in the calculation of phosphorus loads:

$$L := \sum_{i} C_i \cdot Q_i \cdot W \cdot Qf \cdot k$$

$$Qf := \frac{\left[\sum_{w} Q_w\right]}{\left[Q_1 \cdot W\right]}$$

where:

L	= annual phosphorus load (tonnes/annum as phosphorus)
i	= observations 1, 2, 3, ...
C_i	= instantaneous phosphorus concentration at sampling period i (mg/L)
Q_i	= mean daily discharge on day i (m3/sec)
W	= number of days for which the load rate is assumed to be in effect
k	= constant to convert mg/s to tonnes/day
Q_w	= the daily instantaneous flow for each day in the period W

The term Qf corrects for over estimates or underestimates based on the discharge for the period the concentration is assumed to apply.

Mean daily discharge at the South Saskatchewan River at Lemsford (day i) was calculated from the summed daily discharges of South Saskatchewan River at Highway #41 and Red Deer River near Bindloss (day (i-1)). Day (i-1) was chosen based upon time of travel calculations published by the PPWB (PPWB, 1974) which indicate that the time of travel from Highway #41 to Lemsford Ferry ranges from approximately 20 hours at high discharge to 31 hours at low discharge. Hydrometric data from Highway 41 and Bindloss were provided by Water Survey of Canada. Data for 1988 remain provisional at the time of publication. Discharge information for Gardiner Dam were provided by the Saskatchewan Water Corporation.

Sediment sampling on Lake Diefenbaker was conducted from August 30 to September 2, 1988. The samples were collected using a Ponar dredge on lake cross-sections at Cabri Regional Park, Saskatchewan Landing Provincial Park, Goodwin Subdivision, Herbert Regional Park, and Riverhurst Ferry. Four or five samples were taken on each cross-section depending on the width of the lake at the site. The top four cm of sediment from each sample was placed in a plastic bag and frozen. Analysis of the samples was done at National Hydrology Research Centre (NHRC), Saskatoon, Sk.

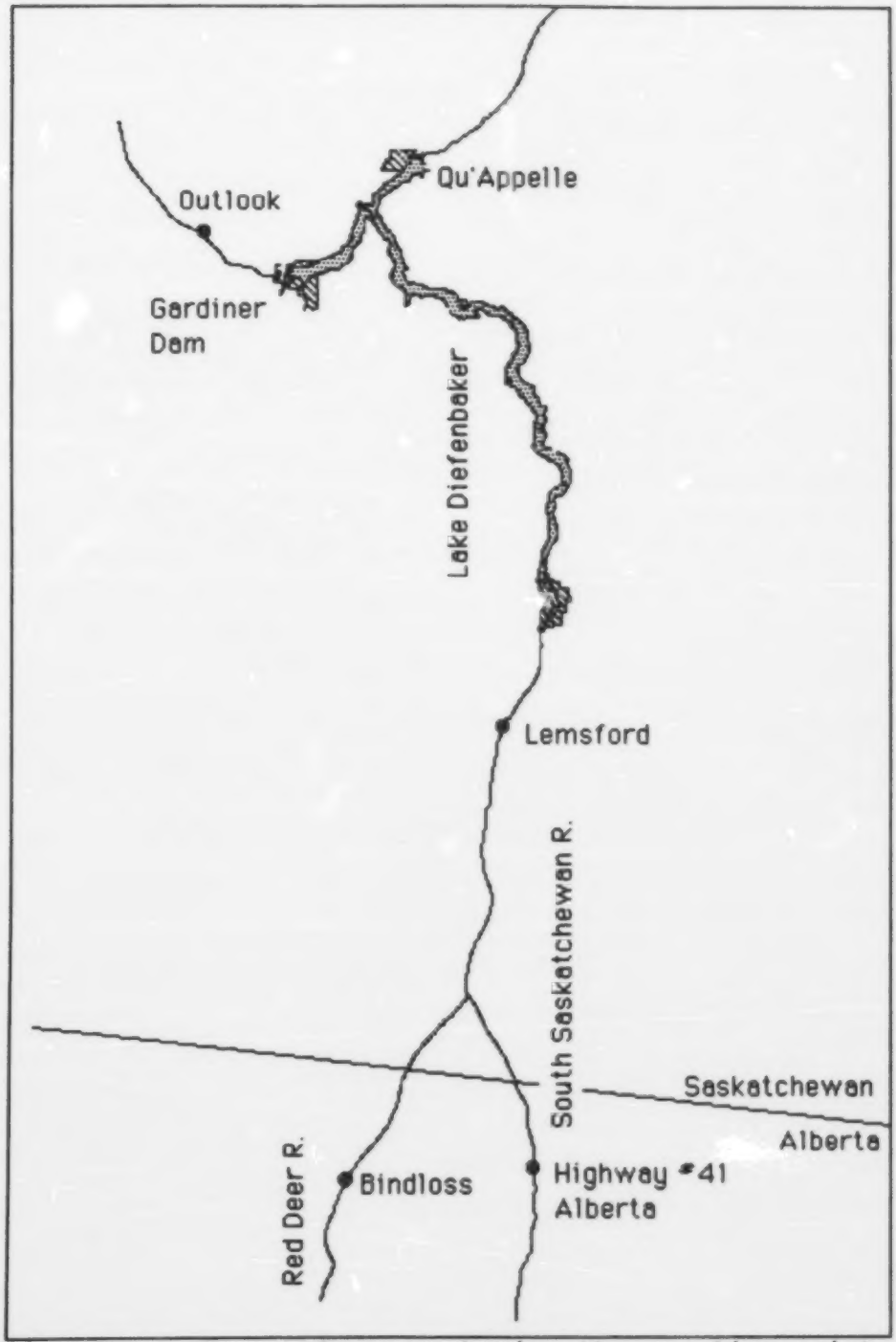


Figure 1: The study area showing the sampling points for Lake Diefenbaker phosphorus loading estimates.

3.0 Results and Discussion

3.1 Phosphorus Load into Lake Diefenbaker Based upon Tributary Data, 1975 to 1988 and Lemsford Data, 1985- 1988.

Tables 1 and 2 summarize the total and dissolved phosphorus loads calculated for the lake based on the two sets of data. Figure 2 presents a comparison of the two data sets.

Table 1: Annual Phosphorus Load to the South Saskatchewan River (Highway #41) and Red Deer River (Bindloss) Monthly Sampling Locations (1975 to 1988)

	Discharge (,000 dam3)		Annual Phosphorus Load (Tonne/Year as phosphorus)			
			Total P		Dissolved P	
Year	SSR	RDR	SSR	RDR	SSR	RDR
1975	4,791	805	1,184	271	---	---
1976	3,648	819	1,682	218	---	---
1977	1,452	747	78	183	---	---
1978	4,160	1,127	923	477	83	27
1979	3,960	990	537	166	131	22
1980	4,610	1,650	822	1,255	178	20
1981	6,920	2,330	866	668	140	23
1982	4,140	1,970	744	730	143	36
1983	2,940	1,240	285	1,335	47	19
1984	2,170	925	132	115	32	8
1985	3,010	1,310	573	276	48	14
1986	5,260	2,370	896	579	82	74
1987	3,410	1,320	271	292	39	38
1988	2,277	1,038	70	145	31	8
Mean	3,768	1,332	647	479	87	26

The discharge data found in Table 1 and 2 was from Water Survey of Canada Annual Hydrometric Publications (1975 to 1987 inclusive), 1988 data provisional at time of publication.

The following points are apparent upon examination of Table 1:

1. TP loading is highly variable from year to year in both rivers. The difference between years can be an order of magnitude or greater.

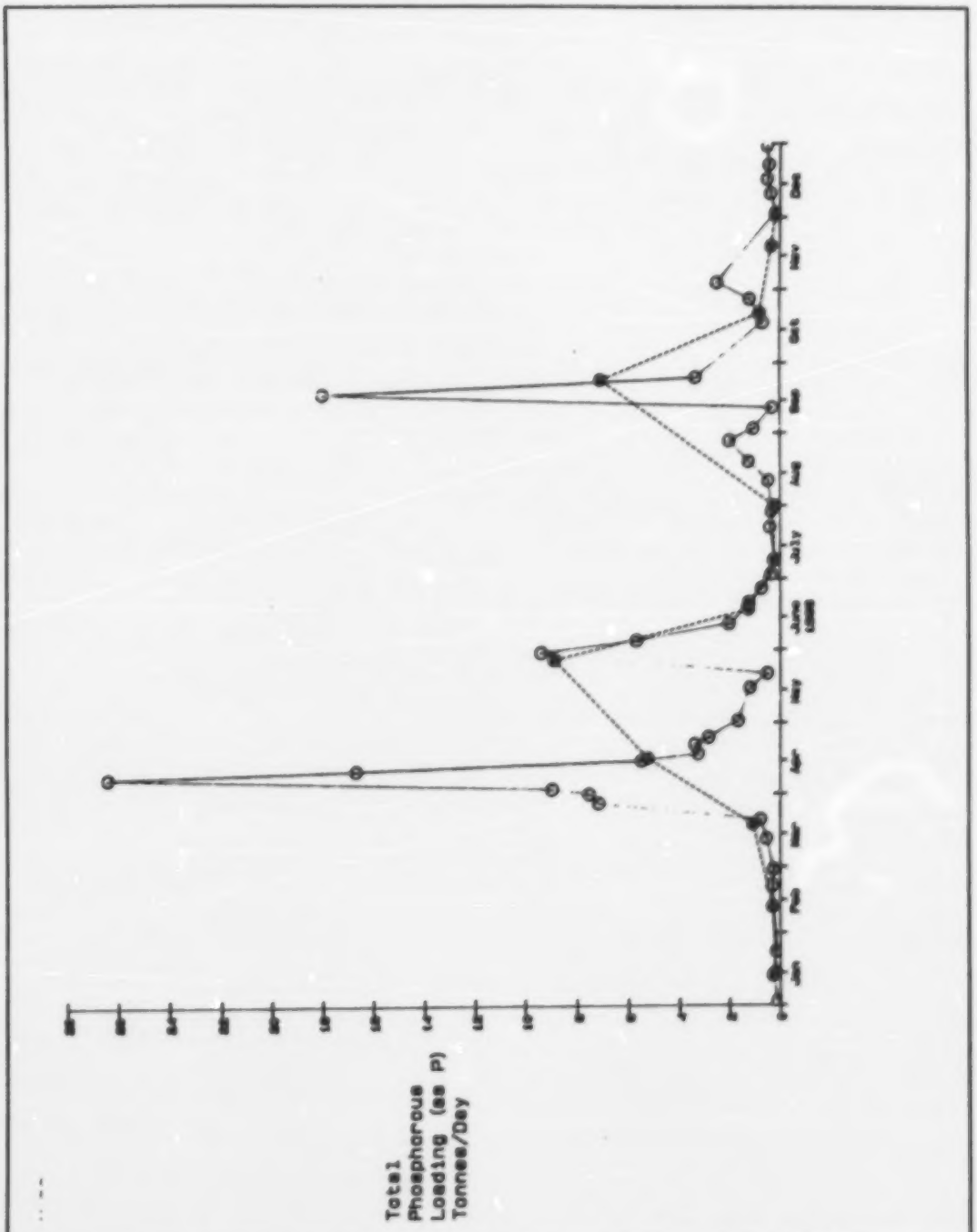


Figure 2: Comparison of the total phosphorus loadings from the tributaries and Lemsford (1985).(-o- = Lemsford data; -●-=SSR and RDR data)

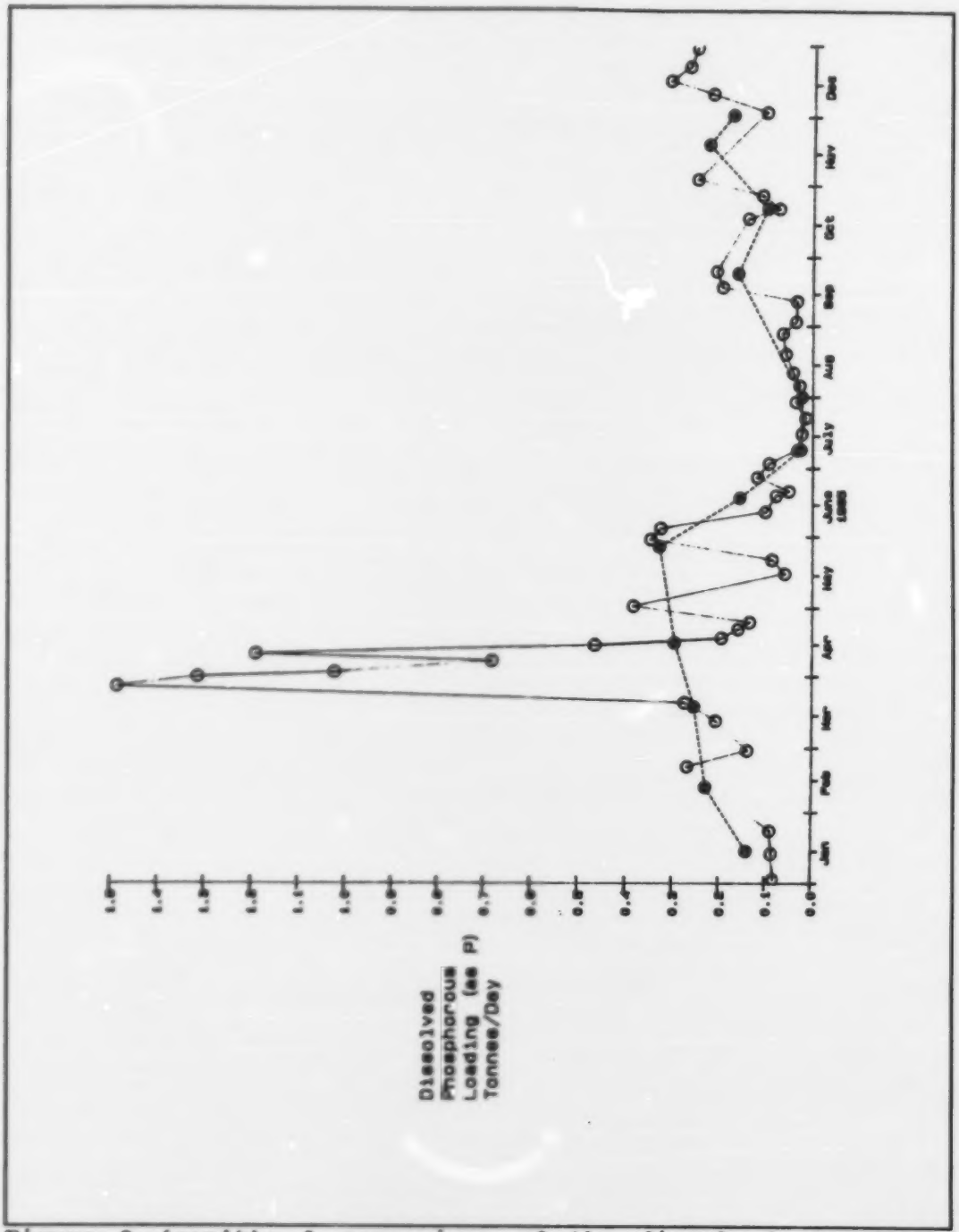
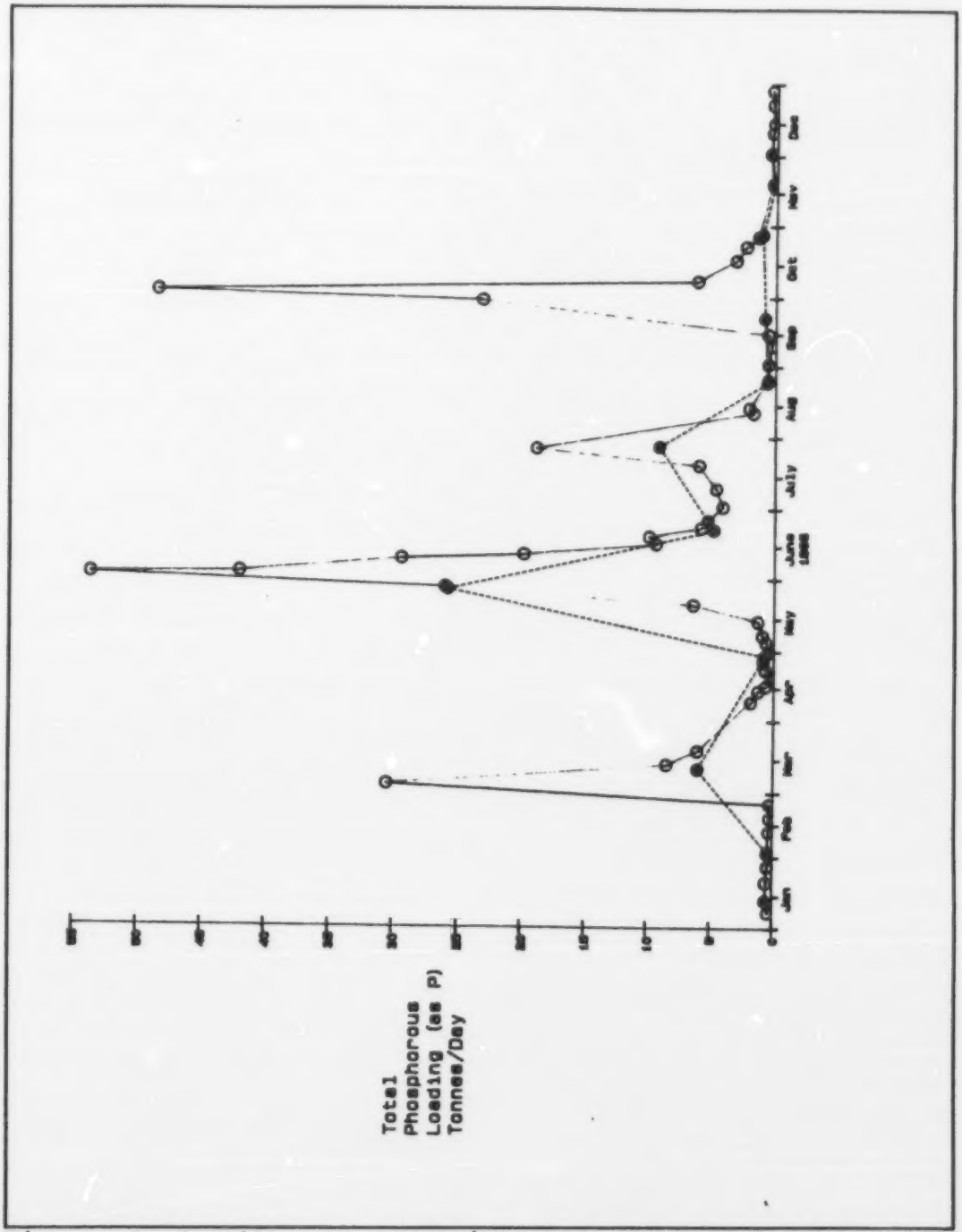


Figure 2 (con't): A comparison of the dissolved phosphorus loadings from the tributaries and Lemsford (1985). (-o- = Lemsford data; -●- = SSR and RDR data)



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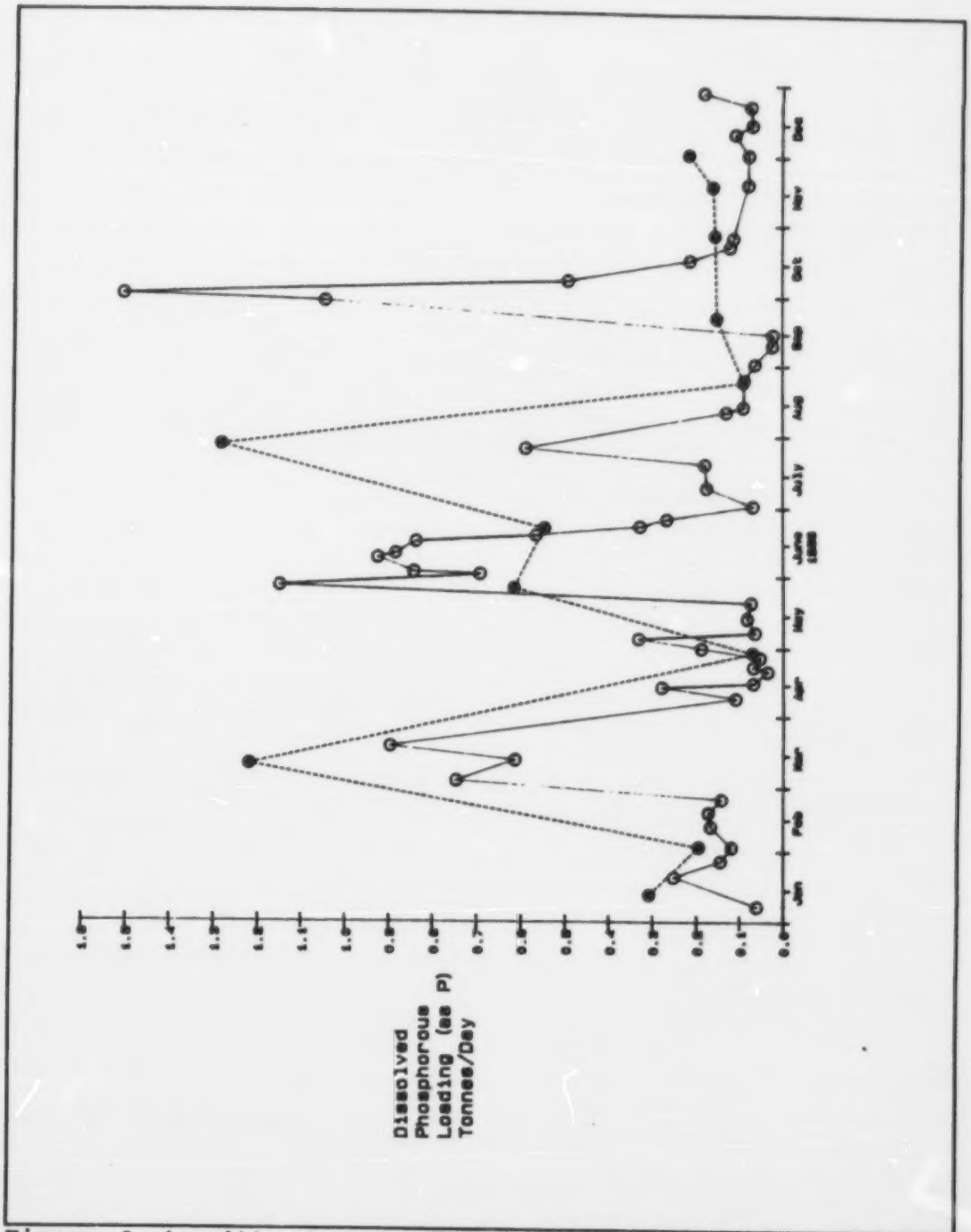

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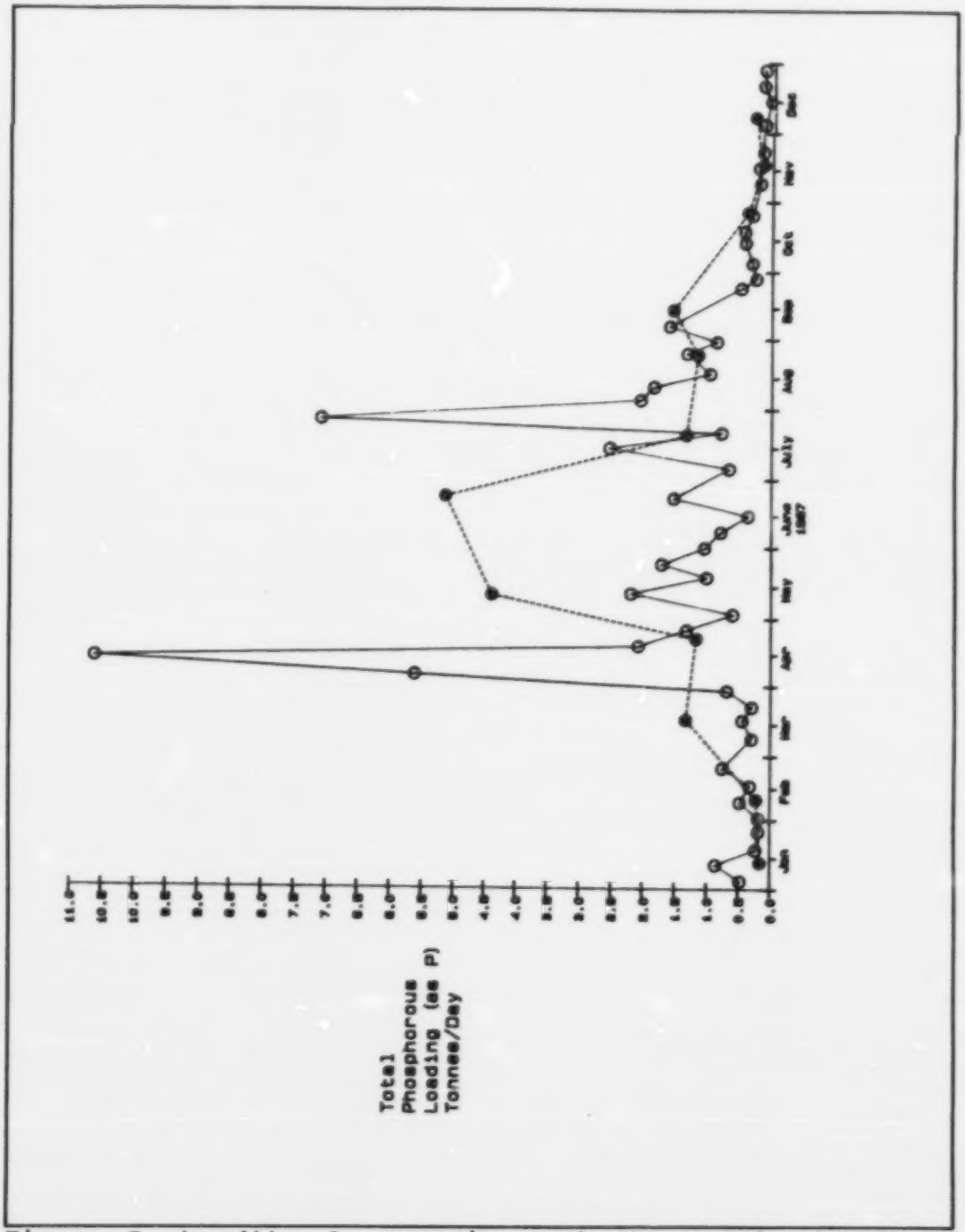

Figure 2 (con't): A comparison of the total phosphorus loadings from the tributaries and Lemsford (1987). (-o- = Lemsford data; -●- = SSR and RDR data)

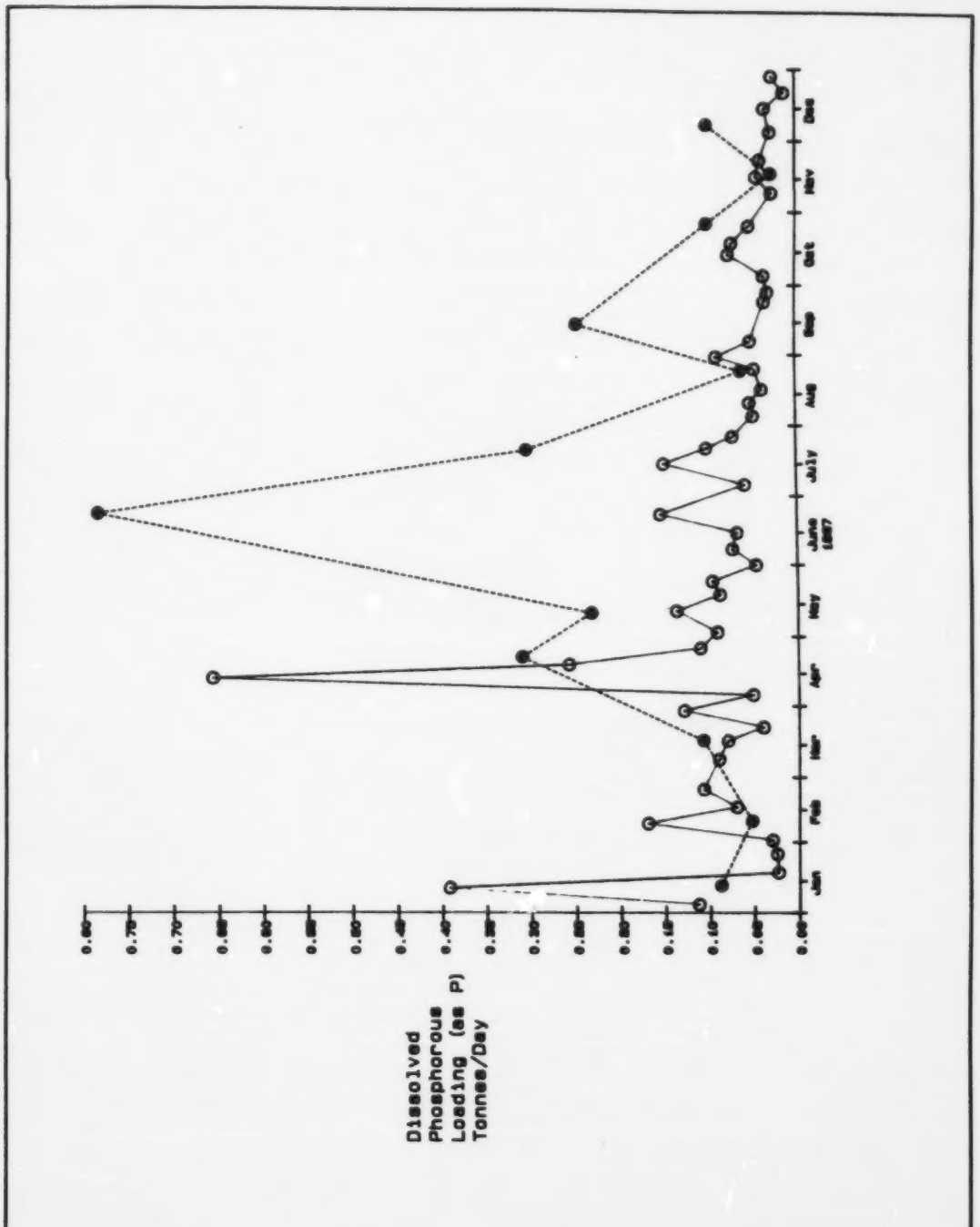

Figure 2 (con't): A comparison of the dissolved phosphorus loadings from the tributaries and Lemsford (1987). (-o- = Lemsford data; -●- = SSR and RDR data)

2. Despite a 3:1 ratio in annual discharge, mean annual TP loading from the SSR is only slightly higher than that of the RDR. In five of the fourteen years of record, TP loading from the RDR exceeded that of the SSR.

3. Dissolved phosphorus (DP) loading is less variable from year to year than TP loading.

4. Mean annual DP loading from the SSR exceeds that of the RDR by a factor of three, in accordance with mean annual discharge.

5. On average, DP comprises 13 percent of the TP loading in the SSR, compared with 5 percent in the RDR.

Phosphorus loads from the tributary sampling locations shown in Table 1 indicate trends that have significant implications for the sources of phosphorus loads to Lake Diefenbaker. The loads were highly variable from year to year in each river and even though the South Saskatchewan River has three times the flow of the Red Deer River it delivers nearly as much total phosphorus to the lake. Variations in the dissolved phosphorus loads in the two rivers were less variable than total phosphorus. The South Saskatchewan River delivering on the average more than three times the dissolved phosphorus than the Red Deer River, this is directly proportional to the differences in the flows of the two rivers.

SE&PS et al. (1988) presented a discussion of seasonal variation in P loading. TP loading from both SSR and RDR was found to be highly seasonal. 83 percent of annual TP loading tended to occur during the period April to July. This results from the strong relationship between particulate phosphorus and suspended sediment, which reach maximum concentration during periods of peak discharge. Seasonal variation in DP loading was somewhat less pronounced than was the case with TP loading (SE&PS et al. (1988). Late winter DP loading was found to be highly significant, with minimal DP loading normally present in the late summer-early winter period. The period January to July accounted for 88 percent of mean annual DP load from the SSR and RDR.

The comparison of P loads calculated from both the tributaries and Lemsford Ferry requires the assumption that real gain or loss in total phosphorus load is not significant between the two monitoring locations. This assumption is reasonable considering the similarity in geography throughout the reach,

the relatively short distance between stations (approximately 75 kilometres), and the lack of significant tributary inputs.

Figure 2 presents a comparison of the loads for 1985 to 1987 for the two sampling locations. Loads for 1986-1987 do not display the same degree of overlay found in 1985. The reason for the variation in these estimates was believed to be the differences in sampling frequencies for thetwo data sets. For the purposes of this discussion, the hypothesis of no net gain or loss in phosphorus load between locations will be assumed.

Table 2 and Figure 2 indicate that using data from the different locations and sampled at different frequencies, can produce substantially different load estimates for phosphorus. Total phosphorus loads from the tributaries differed from the Lemsford site by as much as -48% (1988), and dissolved phosphorus loads by as much as +140% (1987).

Table 2. Phosphorus Load into Lake Diefenbaker Based upon data from Lemsford Ferry and Tributaries, 1975 to 1988

		Annual Phosphorus Load (Tonne/Year as phosphorus)			
	Total	Total P		Dissolved P	
Year	Discharge (,000 dam3)	SSR RDR(1)	Lemsford Ferry(2)	SSR RDR	Lemsford Ferry
1985	4,320	848	1358	62	112
1986	7,630	1475	2164	156	103
1987	4,730	563	414	77	32
1988	3,315	215	414	39	22
Mean	5,000	775	945	84	58

(1) During 1985, n=12; 1986, n=12; 1987, n=12; 1988, n=12
(2) During 1985, n=47; 1986, n=52; 1987, n=47; 1988, n=49

Two reasons were noted for the differences in the estimates:

1) The nature of phosphorus load in the South Saskatchewan R. system (SE&PS et al., 1988) showed that major phosphorus load events can be very short in duration, often shorter than the time between monthly sample collections. A major load event between March 15-April 15 could be underestimated by the monthly tributary samples being collected just before and just after this event. The probability of monthly sampling

overestimating Phosphorus load by 'widening' an event is just as high.

2) The importance of individual results to the accurate determination of phosphorus load increases as sampling frequency decreases. Most load calculations assume static load half-way back to the previous sample, and half-way forward to the next sample. Error in any factor (including concentration through analytical/sampling error) thus causes magnified error in load as frequency is decreased. Field and laboratory quality control is extremely important in low frequency load programs, especially during periods of high discharge.

The implication of these findings are that if all other factors are kept equal, high frequency sampling programs will produce more accurate load results than low frequency programs. An alternative and cost effective approach incorporates variable frequency sampling. To accurately estimate the phosphorus loads to Lake Diefenbaker it is recommended that twenty-four samples per year be collected, with weekly samples during April-July, and monthly samples the remainder of the year. This would tend to lessen the opportunity of missing major input events to the lake that are associated with high flows.

To test this sampling protocol data from the 1985 to 1987 data sets were used. Monthly samples were selected from January to March and August to December and weekly data was selected for the period April to July inclusive. The formula presented earlier in the report (Section 2) was used to calculate the loadings. The results of this analysis are shown in Table 3.

Table 3: A comparison of the loading of Total Phosphorus to Lake Diefenbaker calculated from weekly sampling and calculated from the new sampling protocol (Lemsford data).

	Total Phosphorus (tonnes/year)		
	Weekly	New Protocol	% Difference
1985	1353	1718	21
1986	2164	2284	6
1987	414	490	16

The results from 1985 showed the most variation between the two protocols. Considering that the maximum variation in the calculations was 21% this method of sampling for loadings would be superior to the monthly sampling where the variations could vary as much as 50% (Table 1).

If the objective of the sampling program is to estimate the phosphorus loading to Lake Diefenbaker it is recommended that the

sampling protocol outlined above be carried out at Lemsford rather than the two tributary sites. This will provide a cost effective method of providing loading estimates to the lake.

3.2 Phosphorus Load out of Lake Diefenbaker (Gardiner Dam Data, 1985 to 1988)

Table 4 presents a comparison of phosphorus loads entering and leaving Lake Diefenbaker. The data for the table were taken from the weekly sampling at Lemsford and Gardiner Dam.

On average, annual total phosphorus loads entering Lake Diefenbaker exceed those leaving the Lake by a factor of 26:1, and Dissolved phosphorus loads by a factor of 4:1. Year to year variability in phosphorus load (and seasonal variability in phosphorus concentration (SE&PS et al., 1988) was much lower at Gardiner Dam than at Lemsford Ferry (Table 3).

The average total phosphorus leaving Lake Diefenbaker via Gardiner Dam from 1985 to 1988 was 36 tonnes/annum. This means that under average circumstances the lake accumulated 909 tonnes of total phosphorus per year. Dissolved phosphorus entering Lake Diefenbaker is utilized relatively quickly by plant communities in the upper reaches of the lake (SE&PS et al., 1988). A significant proportion of this phosphorus is recycled within the planktonic community as the water moves downstream in the lake. The portion of the dissolved that is lost to the water column settles to the bottom as organic phosphorus associated with algae. The particulate portion of the total phosphorus load sediments from the water column relatively quickly. These two factors result in Lake Diefenbaker becoming a significant sink for phosphorus.

Table 4. A Comparison of Phosphorus Load at Lemsford Ferry and Gardiner Dam, 1985 to 1988

	Discharge (,000 dam3)		Phosphorus Load (Tonnes/Year as phosphorus)			
			Total P		Dissolved P	
Year	Lemsford Ferry	Gardiner Dam	Lemsford	Gardiner	Lemsford	Gardiner
1985	4,320	2,819	789	23	73	13
1986	7,630	5,161	2164	48	103	21
1987	4,730	4,933	414	47	32	21
1988	3,315	2,724	414	26	22	9
Mean	5,000	3,910	945	36	58	16

During 1985-1988, n=195 at Lemsford Ferry; n=171 at Gardiner Dam

It should be noted that phosphorus entering and leaving Lake Diefenbaker via the South Saskatchewan River do not completely describe the lake's phosphorus balance. Non-point source phosphorus inputs include land runoff and atmospheric deposition, estimated by SE&PS (1988) to total approximately 150 tonnes total phosphorus/annum. As well, phosphorus loss occurs to the Qu'Appelle River via the Qu'Appelle Dam, estimated to average less than 5 tonnes total phosphorus/annum (K. Weagle, pers. comm). These factors are significantly outweighed by the influence of the South Saskatchewan River.

3.3 Phosphorus Composition of the Sediments

Table 5 presents phosphorus-fractionation data for Lake Diefenbaker bottom sediments collected during October, 1984 and September 1988.

Table 5: Bottom Sediment Phosphorus Fractions from Lake Diefenbaker, October 1984 and September 1988.

Location	Total P	Inorg P	Apatite P	NAI P	Org P
			1984		
Sask. Landing	851	770	393	376	82
Range 11	906	758	316	442	148
Herbert Ferry	744	724	364	360	02
Snakebite Creek	669	632	298	334	73
Riverhurst Ferry	752	726	413	312	62
Mean Upper End	784	722	357	365	36
Hitchcock Coulee	636	605	382	223	23
Range 4 Elbow	848	728	451	277	115
Range 4 Elbow	880	827	384	442	45
Range 3 Elbow	878	778	384	394	100
Range 2	996	803	395	408	193
Danielson Park	968	875	370	505	49
Mean Low End	874	754	381	374	119
			1988		
Cabri Park	592	526	317	208	67
Ssak. Landing	695	647	354	294	48
Goodwim Subdivis.	664	611	349	263	53
Herbert Ferry	715	633	299	335	82
Riverhurst	771	678	380	303	92

All results in mg/kg sediment (as phosphorus)

Pierrou (1974) reported that the total abundance of inorganic phosphorus in the top one metre of soil on the earth's surface is

approximately 0.10-0.12 percent. This corresponds to 1000-1200 mg/kg, slightly higher than found in the bottom sediments of Lake Diefenbaker. Freshwater plants, Pierrou stated, typically contain 0.5 percent phosphorus, other types of biomass are estimated at 1.0 percent phosphorus, and river sediments at 0.075 percent phosphorus.

Total phosphorus concentrations in-lake reported in SE&PS (1988,a) showed that sedimentation of particulate phosphorus occurs in the upper half of the lake above Herbert Ferry. The relatively homogenous phosphorus fractionation found through the upper and lower reaches of Lake Diefenbaker, together with the fact that total phosphorus concentration in the bottom sediments closely corresponds with typical soil data, supports the conclusion that aquatic particulate phosphorus entering the lake via the South Saskatchewan River is the result of natural erosive sources.

The rate of phosphorus release from bottom sediments is controlled by a number of factors (oxygen content of the bottom waters, sediment-water interface, and particulate Phosphorus fractions present (Horne, 1978; and Sonzogni, 1982)). Release of phosphorus from bottom sediments underlying well-oxygenated waters is generally minimal, due to the chemistry of metal-phosphorus equilibria (Horne, 1978). SE&PS et al. (1988) stated that thermal stratification in Lake Diefenbaker was not observed during the 1984-85 study period. Generally, oxygen concentration was high and uniform with depth, and bottom oxygen depletion was rare. Under these conditions phosphorus leaching from the bottom sediments would have been limited.

The bottom sediments of Lake Diefenbaker (Table 4) are composed of approximately 45 percent apatite inorganic phosphorus, 45 percent non-apatite inorganic phosphorus (NAIP), and 11 percent organic phosphorus. Inorganic phosphorus in apatite minerals is essentially non-available biologically. NAIP, which is normally composed of Fe and Al hydrous oxides and minerals, is partially biologically available. While in suspension, NAIP may be utilizable by algae (Sonzogni, 1982). Following sedimentation, phosphorus leaching is controlled by the levels of oxygenation. Particulate organic phosphorus can be utilized to some degree biologically. Utilization is much more substantial for fresh plant tissue and animal waste than for soil and sediment organic-phosphorus forms (Sonzogni, 1982).

Sonzogni summarized the findings of a number of workers who had estimated phosphorus bioavailability in the suspended sediments from several different water sources. These are listed in Table 6.

Table 6: Estimates of Bioavailability of Sediment TP from Several Different Water Sources (from Sonzogni et al.,1982)

Water Source	Potential Bioavailability
Several Tributaries to the Great Lakes	40 percent or less
Agricultural Drainage	20 percent
Urban Drainage	25-30 percent
Recessional Shorelines in Ohio and Michigan	1-11 percent
Atmospheric inputs	25-50 percent
Municipal waste-water	70-100 percent

Figures 3 and 4 show the available (NAIP + Organic Phosphorus) and organic phosphorus composition of the sediments of Lake Diefenbaker. Assuming that all NAIP is available for biological activity means that approximately 55% of all sediment phosphorus would be available. This would provide a large pool of phosphorus available for entry into the water column if the oxygen availability was reduced. It is conceivable that if oxygen were to be reduced for extended periods in either summer or winter, the phosphorus released from the sediments would be of sufficient quantity to cause the lake to assume a more eutrophic state. Although there are few circumstances, that are anticipated at present, that could cause extended oxygen depletion of the lake, all future developments in the area of the lake or upstream should be evaluated with this in mind.

3.4 Water Quality Objectives for Phosphorus in the South Saskatchewan River Upstream of Lake Diefenbaker

Several factors have to be taken into account in developing phosphorus objectives for the South Saskatchewan River upstream of Lake Diefenbaker. The most important factor is the maintenance of the trophic state of the lake. The second factor is the dynamics of the phosphorus species after they enter the lake; and third is the form of phosphorus that enters the lake.

The results of this study have indicated that the most prevalent form of phosphorus entering the lake is particulate (85-90%) and the major source of this phosphorus is hypothesised to be natural erosion. This form of phosphorus settles out of the water column within the upper reaches of the lake. Approximately 50% of the particulate phosphorus is Apatite (not available for biological activity) and the rest is Non-Apatite (available for biological activity under certain conditions, i.e. low oxygen).

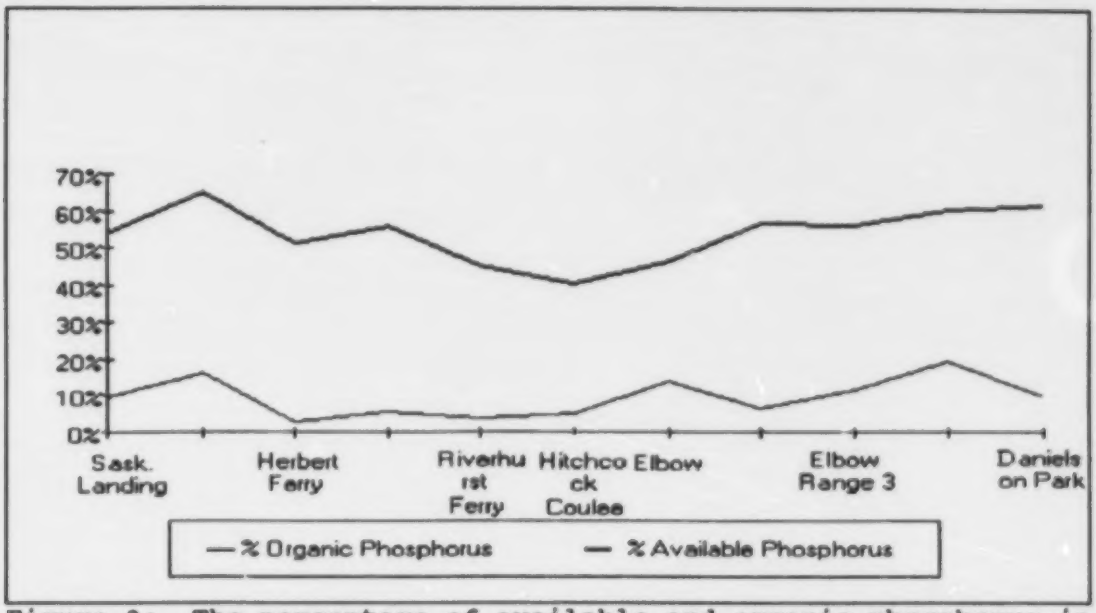

Figure 3: The percentage of available and organic phosphorus in the sediments of Lake Diefenbaker (1984 data).

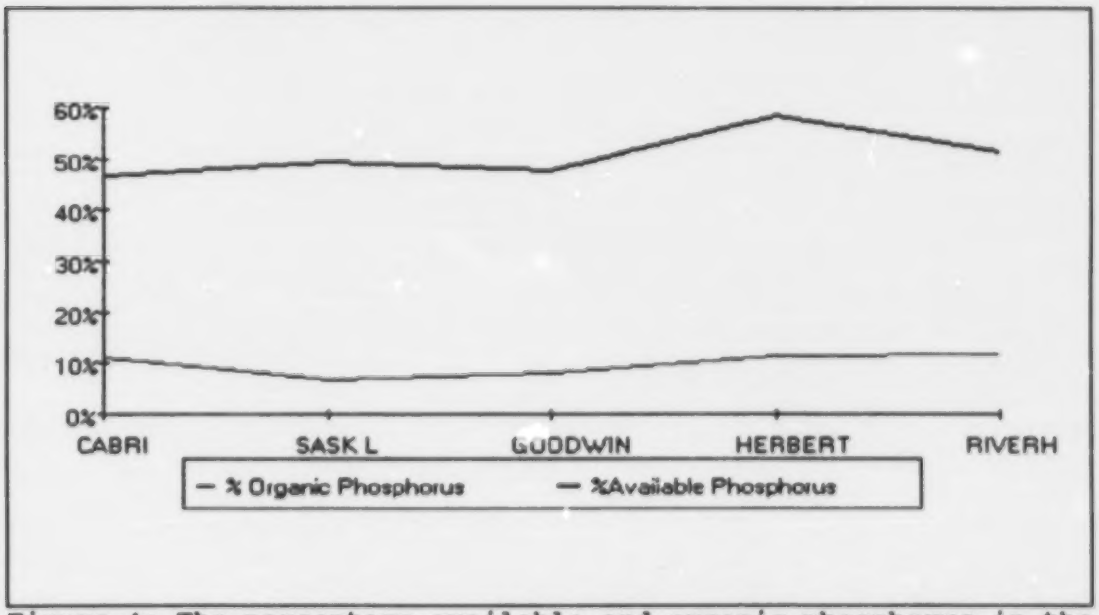

Figure 4: The percentage available and organic phosphorus in the sediments of Lake Diefenbaker (1988 data).

The remaining 10% of the phosphorus entering the lake is in a dissolved form and is assumed to be immediately available for biological activity.

The trophic state model for the lake (SE&PS et al., 1988) indicates that most of the biological activity in the lake occurs upstream of Riverhurst Ferry. In this area the available phosphorus in the water column is at a maximum and maximum chlorophyll a levels are recorded in the summer months. It has also been noted that the high sediment levels in the water column in the Saskatchewan Landing area reduce planktonic growth by reducing light penetration. At the point in the lake where the sediment has settled and the phosphorus is high (Herbert Ferry) we observed the highest biological activity (SE&PS et al., 1988). The trophic state model indicated that extensive amounts of dissolved phosphorus would have to be present in the inflow to the lake to affect areas of the lake downstream of Riverhurst.

With the particulate phosphorus input to the lake coming from natural sources and playing a minor role in biological activity (Trophic State) it is proposed that the only a dissolved phosphorus objective should be considered for the South Saskatchewan River upstream of Lake Diefenbaker. The development of this objective is not possible at present because the present trophic state model is based on total phosphorus (particulate + dissolved). The present low inputs of dissolved phosphorus to the lake and the lack of anticipated developments that would increase this parameter make the development of the objective less critical than origionally anticipated.

Although a phosphorus objective may not be necessary, the fact that Lake Diefenbaker is a phosphorus sink, makes it imperative that all projects on the lake and upstream of the lake, be evaluated in light of changes to the dissolved oxygen regime in the lake. This will be more critical than the development of upstream phosphorus objectives.

4.0 Conclusions

1. The most accurate and cost effective sampling protocol for sampling phosphorus input to Lake Diefenbaker would be monthly sampling from January to April and August to December with weekly sampling from April to July.

2. Lake Diefenbaker is a sink for phosphorus within the South Saskatchewan River basin with little or no regeneration of phosphorus from the sediments at present.

3. Sediments in Lake Diefenbaker contain as high as 55% biologically available phosphorus. This makes it imperative that new developments do not alter the oxygen regime of the lake so that the phosphorus is released to the water column.

4. No water quality objective for phosphorus in the South Saskatchewan River upstream of Lake Diefenbaker was developed. If one is to be developed in the future it should be for dissolved phosphorus.

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